

3D modelling of the hunting palace in Julin using terrestrial laser scanning and photogrammetry

Przemysław Leń¹,  0000-0003-0810-9986

Magdalena Kuzdak²

Klaudia Maciąg³  0000-0003-4099-9886

Michał Maciąg³  0000-0002-8745-0009

Karol Ożóg⁴  0000-0002-2464-9010

¹ Department of Geodesy and Geotechnics, Faculty of Civil and Environmental Engineering and Architecture, Rzeszów University of Technology

² Podkarpackie Office of Geodesy and Agricultural Lands in Rzeszów

³ Department of Geodesy and Spatial Information, University of Life Sciences in Lublin

⁴ Vice-Marshall of the Podkarpackie Voivodeship, Marshal's Office of the Podkarpackie Voivodeship

✉ Corresponding author: p.len@prz.edu.pl

Summary

The paper presents the development of a 3D model of the hunting palace in Julin using terrestrial laser scanning (TLS), along with complementary photogrammetric documentation. The study concerned a historic wooden building of high cultural value and complex architectural form located in the Podkarpackie region in south-eastern Poland. The main objective was to obtain a metrically reliable digital record that could support architectural inventory, conservation planning and future monitoring of the monument. Field work included TLS measurements of the exterior, roof and accessible interiors, as well as terrestrial and UAV-based image acquisition. The processing stage entailed point cloud registration, cleaning and filtering, integration of image data, generation of a textured mesh model, preparation of façade orthophotoplans, and drafting of the front elevation. In total, 218 scanner stations were used to create one coherent spatial dataset, and the final general registration error amounted to 1.110 mm, confirming high geometric reliability of the survey. The comparison of the orthophotoplan with the technical drawing of the front façade confirmed the dimensional consistency of the developed materials. The results indicate that the integration of TLS and photogrammetry enables comprehensive documentation of architecturally complex heritage buildings and provides products of high

metric, analytical and visual quality. The resulting documentation may support conservation, renovation, digital presentation and long-term management of historic wooden architecture.

Keywords

terrestrial laser scanning • photogrammetry • heritage documentation • 3D model • orthophotoplan • Julin

1. Introduction

Contemporary heritage protection increasingly relies on digital technologies that enable precise, non-invasive and repeatable documentation of historic buildings [Markowski 2020]. Among these methods, terrestrial laser scanning plays a particularly important role because it makes it possible to acquire dense point clouds, and to generate detailed spatial models of architectural objects [Markowski 2020, Xu et al. 2018, Markiewicz and Nowak 2018]. Such an approach is important not only for inventory and archival purposes, but also for monitoring the state of preservation, planning conservation works, and preparing source material for design studies [Markowski 2020, Xu et al. 2018]. As indicated by Klapa [2023], data acquired with TLS and UAV photogrammetry can form the basis for HBIM models used for documentation, conservation, renovation and visualisation of heritage buildings.

Recent international literature confirms that TLS has become one of the key methods used in the documentation of heritage objects, especially when high geometric fidelity, repeatability of measurements and the possibility of combining multiple sources of spatial data are required [Costantino et al. 2021, Remondino and Campana 2014]. Studies published in leading journals emphasise that point clouds obtained from laser scanning can be effectively integrated with image-based modelling, semantic classification and HBIM environments, while significantly expanding the analytical value of survey data and supporting conservation decision-making [Apollonio et al. 2021, Tucci et al. 2017]. This research trend shows that digital inventories are no longer treated solely as archival records, but increasingly as dynamic information resources used for diagnosis, simulation and long-term monument management.

International publications also emphasize that the quality of TLS-based documentation depends not only on scanner accuracy, but also on survey design, station geometry, point cloud registration strategy, filtering procedure and the integration of data with photographic material [Fassi et al. 2011, Xu et al. 2018]. In the case of architecturally complex buildings, especially historic ones with decorative detail and irregular geometry, a multi-sensor workflow is considered more robust than relying on a single technique [Costantino et al. 2021]. The literature further points out that textured 3D models and orthophotoplans generated from integrated datasets improve the interpretative potential of inventory material by combining geometric reliability with visual readability [Moyano et al. 2021, Tucci et al. 2017].

The hunting palace in Julin is a valuable example of wooden residential architecture in the Podkarpackie region, combining historical, cultural and technical significance [Urząd Gminy w Rakszawie 2025, Sapeta 2025]. The building is located within

the Wydrzańskie Forests in the north-eastern part of Wydrze village, in the Rakszawa commune [Urząd Gminy w Rakszawie 2025]. Its architectural structure, decorative detail and former representational function justify the need for accurate digital documentation, particularly in the context of heritage protection and planned revitalisation works [Sapeta 2025]. Wooden structures are especially susceptible to weathering, biological degradation and local deformations, which makes detailed digital recording particularly important for future comparison and monitoring.

The objective of the study was to develop a detailed 3D model of the hunting palace in Julin using terrestrial laser scanning and mesh modelling techniques, and to assess the usefulness of the resulting digital products for inventory and conservation purposes. The study also sought to verify whether the integration of TLS, photographic documentation and photogrammetry enables the preparation of a digital record accurate enough for architectural analysis and conservation practice. In a broader perspective, the paper responds to the current methodological discussion on how to optimise digital heritage workflows so that they support both metric documentation and practical conservation management.

2. Material and methods

2.1. Study object

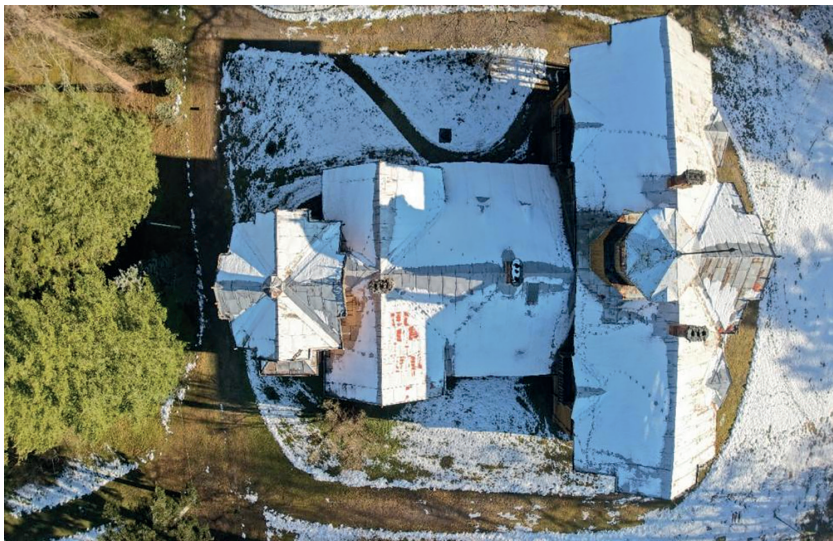
The hunting palace in Julin is one of the most valuable examples of wooden architecture in the Podkarpackie region and represents the Tyrolean-Swiss style [Sapeta 2025]. The building has a plan approximating the letter ‘T’, with a dominant two-storey central



Source: Authors' own elaboration based on the attached study

Fig. 1. Front view of the hunting palace in Julin

body and side wings. Decorative wooden details, a complex roof form and a central tower are among its most characteristic features [Sapeta 2025]. Historically, the palace was associated with the Łańcut Estate and the hunting traditions of the landed aristocracy [Urząd Gminy w Rakszawie 2025].



Source: Authors' own elaboration based on the attached study

Fig. 2. Aerial view of the hunting palace in Julin

2.2. Data acquisition

The research procedure included field measurements and office processing. Field work began with the planning of scanner stations and image acquisition geometry. The palace was first scanned externally and then internally in all accessible rooms. The attic was omitted because it was inaccessible for the scanner. Simultaneously, photogrammetric acquisition was carried out for the façades, the roof, and selected representative interior rooms on the ground floor in the southern part of the building. Ground-level photographic documentation was acquired using a Sony A7 III camera covering all elevations and architectural details, with images collected from multiple viewpoints ensuring a minimum overlap of 60% between adjacent frames. Aerial photogrammetric acquisition was performed using two UAV platforms: a DJI Air 3S for the façade and close-range roof missions, and a DJI Matrice 350 RTK for nadir and oblique missions over the roof. The UAV flights concentrated particularly on the front façade and the roof structure, which are both architecturally significant and difficult to access from ground level. The façade mission was executed at a standoff distance of approximately 8–12 m with the camera gimbal set at an oblique angle, while the roof nadir mission was flown at an altitude of approximately 25 m above the ridge. Image overlap in both missions

was no less than 80% in the forward direction and 70% laterally. Georeferencing of the photogrammetric block was supported by ground control points (GCPs) measured with a Sirius E600 GNSS receiver; the GCPs were distributed evenly around all four elevations of the building and were identifiable in both the scanner data and the imagery, enabling consistent integration of the two datasets.

The main surveying instrument was the Trimble X9 terrestrial laser scanner, supported by a Sony A7 III camera, a DJI Air 3S and a DJI Matrice 350 RTK UAV, and a Sirius E600 GNSS receiver [Geotronics 2025]. According to the technical specification, the Trimble X9 scanner offers a range from 0.6 m to 150 m, distance accuracy of ± 2 mm, angular accuracy below $16''$, 3D point accuracy of 2.3 mm at 10 m and a scanning speed exceeding one million points per second [Geotronics 2025]. The scanner is equipped with three co-axial calibrated cameras of 10 MP each, enabling simultaneous acquisition of high-resolution RGB imagery. The applied workflow is consistent with methods commonly used in architectural inventory and heritage modelling described in the literature [Markowski 2020, Xu et al. 2018, Klapa 2023].



Source: Authors' own elaboration based on the attached study

Fig. 3. Trimble X9 laser scanner used during field measurements

2.3. Data processing

The acquired point clouds from individual scanner positions were imported into Trimble Perspective software for initial quality control and then registered into one common coordinate framework in Trimble RealWorks using the automatic cloud-to-cloud matching algorithm based on overlapping scan data. The registration stage

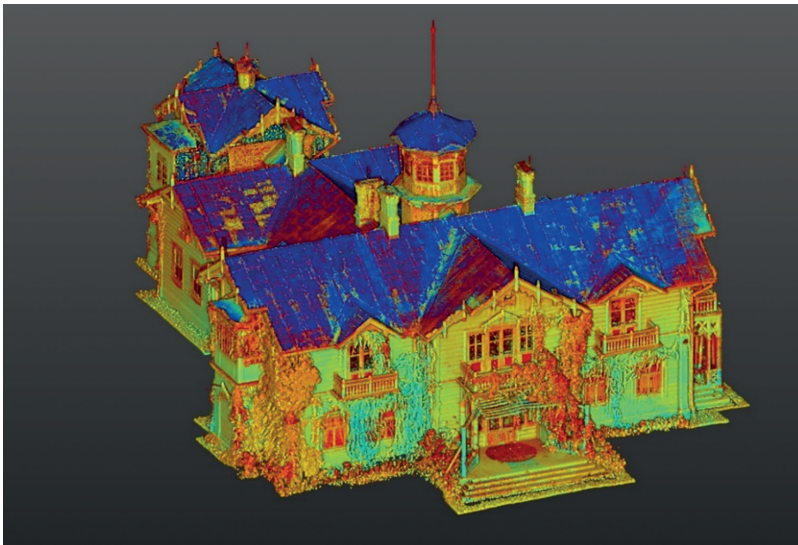
was followed by cleaning and filtering, including the removal of vegetation, random objects, people, noise and points unrelated to the object itself [Markowski 2020, Xu et al. 2018, Markiewicz and Nowak 2018]. Subsequently, the point cloud was integrated with photographic material in RealityCapture, which enabled the generation of a mesh model and the application of textures.

On the basis of the resulting model, orthophotoplans of the façades were generated. In addition, the point cloud was used in MicroStation to prepare the technical drawing of the front elevation. According to the cited literature, this type of workflow is particularly effective when geometric accuracy and visual completeness are equally important [Klapa 2023, Designing Buildings 2025].

3. Results and discussion

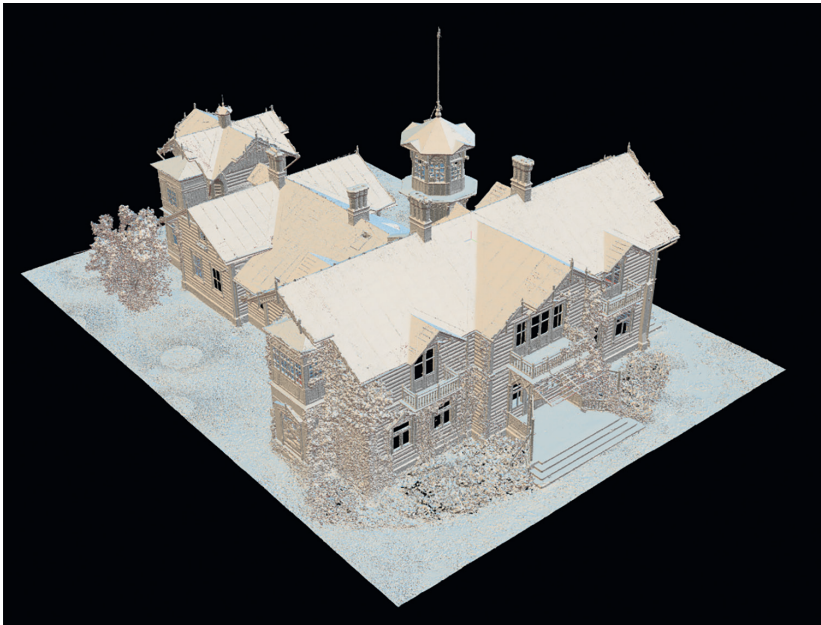
A total of 218 scanner stations were used and combined into one coherent spatial dataset. The final general cloud-to-cloud registration error amounted to 1.110 mm, which indicates high geometric consistency of the resulting point cloud. Selected stations achieved local joining errors in the range of approximately 0.307–0.562 mm, confirming the proper arrangement of the survey network and the effectiveness of the registration procedure.

The final products of the work included a complete point cloud, a 3D model, a textured mesh model, orthophotoplans of the façades, a front elevation drawing, and photographic documentation. The point cloud covered the façades, the roof and all accessible interiors, enabling the detailed representation of the geometry and architectural detail of the palace.



Source: Authors' own elaboration based on the attached study

Fig. 4. Point cloud of the hunting palace in Julin



Source: Authors’ own elaboration based on the attached study

Fig. 5. Mesh 3D model of the hunting palace in Julin

An important result was the comparison of the orthophotoplan with the technical drawing of the front elevation. The basic dimensions were consistent, including the maximum façade height of 10.99 m, the width of the central part of 21.40 m and the total width of the front elevation of 25.52 m. This confirms the metric correctness of the developed products and the usability of orthophotoplans as a source for further analysis and design work. The key accuracy parameters of the survey and a comparative overview of the dimensions derived from both products are summarised in Table 1.

Table 1. Summary of key accuracy parameters and dimensional comparison between orthophotoplan and technical drawing (front façade)

Parameter	Orthophotoplan	Technical drawing	Difference
General cloud-to-cloud registration error	1.110 mm	–	–
Best local joining error (station 58)	0.307 mm	–	–
Maximum local joining error range	0.307–0.562 mm	–	–
Maximum façade height	10.99 m	10.99 m	0.00 m
Width of central part of façade	21.40 m	21.40 m	0.00 m
Total width of front façade	25.52 m	25.52 m	0.00 m

The results confirm the high usefulness of terrestrial laser scanning in the documentation of historic wooden buildings [Markowski 2020, Xu et al. 2018]. One of the major strengths of the adopted approach was the possibility of obtaining detailed geometric and visual data without interfering with the structure of the monument itself. In the case of the Julin palace, this was especially important because of the building's complex body, tall tower, developed roof geometry, and numerous decorative details.

The study also showed that TLS alone does not fully satisfy all documentation needs, especially with regard to surface texture, roof coverings and parts that are difficult to observe from ground level. Here, photographic documentation and UAV-based photogrammetry significantly improved the completeness of the final model. This confirms the methodological validity of integrating multiple surveying methods for heritage documentation, similarly to the conclusions presented by Klapa [2023].

From the conservation perspective, the complementarity of orthophotoplans and technical drawings is of particular value. A technical drawing provides a clear schematic representation of geometry, whereas an orthophotoplan additionally shows the real appearance of the surface, including discolouration, moisture traces, and local damage. Therefore, the most complete documentation effect is achieved by combining both forms.

One limitation of the study was the lack of access to the attic, which means that the final model does not include all internal spaces of the building. Nevertheless, this limitation did not significantly reduce the completeness of the documentation of the external form and principal interior spaces. In future work, it would be advisable to extend the scope by surveying inaccessible spaces, carrying out deformation analyses, integrating the results into BIM/HBIM environments and using repeated surveys to monitor changes in the condition of the building over time.

4. Conclusions

The conducted research demonstrated that terrestrial laser scanning supported by photographic documentation and photogrammetry enable the effective preparation of a detailed 3D model of a historic architectural object. The final products have high metric, analytical and visual value, and therefore can serve as a basis for conservation, design, educational and promotional activities.

In the case of the hunting palace in Julin, the adopted methodology made it possible to faithfully reproduce the building geometry and prepare multi-aspect digital documentation. The achieved registration error of 1.110 mm and the dimensional consistency between the orthophotoplan and the technical drawing confirm the reliability of the obtained data.

A particularly important conclusion is that the integration of TLS and photogrammetry reduces the typical weaknesses of each method when used separately. TLS ensured high geometric accuracy and completeness of the façades and interiors, whereas the photographic and UAV-based data improved the representation of textures and hard-to-reach upper parts of the building. This prompts the conclusion

that a complementary multi-source approach is the most effective for the digital documentation of heritage buildings.

The presented results are consistent with current scientific trends described in the international literature, including papers published by MDPI, which indicate that the most useful TLS-based heritage workflows are those that combine high-accuracy geometry with enriched semantic, radiometric, and management-related information. This means that the value of laser scanning should not be reduced to measurement precision alone. Its real advantage lies in creating a comprehensive digital knowledge base that can support diagnosis of building condition, comparative analyses, design interventions, and long-term data management.

Another practical conclusion concerns the usefulness of derivative products such as orthophotoplans and textured mesh models. Orthophotoplans can support the identification of damage, deformations and surface changes as well as enabling additional measurements without returning to the site. Textured mesh models, in turn, provide not only a realistic visualisation of the object, but also a durable digital record of its current condition. In this respect, the final output of scanning should be understood as a set of interoperable products rather than a single model.

The digital documentation prepared for the Julin palace has significance beyond inventory itself. It can become a strategic resource for planning renovation works, reconstructing architectural details, preparing design studies, and implementing future condition monitoring. This is especially relevant in the case of wooden buildings, which are more vulnerable to weathering and biological degradation. Repeated surveys performed in the future could facilitate comparing successive point clouds and quantifying geometric or material changes in time, which would significantly strengthen preventive conservation strategies.

The research also confirms that the usefulness of TLS grows when the resulting datasets are structured in a way that facilitates future integration with HBIM, GIS or digital archive platforms. Such approach would allow the Julin palace documentation to evolve from a static survey product into a broader information environment supporting management, interpretation and public access to heritage resources.

At the same time, the study confirms that the resulting 3D model and visual materials may also be used in education, exhibition practice, promotion and tourism, increasing access to the site for users who cannot directly visit the monument. In this way, digital documentation contributes to both heritage protection and broader dissemination of cultural values.

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